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An Analysis of the Light Distribution of Street Lanterns

By J. M. WALDRAM, B.Sc., F.Inst.P. *(Fellow)*

Introduction

The performance of street lanterns is usually portrayed by polar diagrams showing the candlepower distribution in selected vertical planes, and over a conical surface including the maximum intensity, or by isocandle diagrams. The correlation of the appearance of the curves and diagrams with the appearance of the lighted street is, however, not simple; several attempts have been made to elucidate the mysteries of isocandle diagrams and to provide methods of plotting more likely to convey an impression of probable performance [1,2].

The present note records a method of analysing the performance as recorded on the isocandle diagram which is particularly difficult to interpret without assistance. It is based upon the conception that the function of a lantern is to make the road and other backgrounds bright, and on the theory of formation of bright patches on the road surface, which is now well established [3]. It deals mainly with unrestricted distributions and staggered arrangements for traffic routes, but can be applied more widely.

(1) Relation Between Bright Patch on Road and Isocandle Diagram

A traffic route lantern suspended over a normal carriageway produces a bright patch of the general shape shown as perspective in Fig. 1, as seen by a road user in a typical position. It has been pointed out [2,3] that the parts of the light distribution which form the large and useful "tail" of the patch are very small; and in Fig. 1 the patch has been divided into zones the boundaries of which are indicated by the angle to the vertical at which light has to leave the lantern to reach them. A large part of the tail is formed by light emerging between 81 deg. and 82 deg. from the vertical. The head, which is much wider, but shallow, is formed by light emitted over much greater zones. Some previous attempts to analyse the polar curve of light distribution in vertical planes have taken account of this fact.

It is, however, possible to relate the polar distribution to the appearance of the patch not in one plane only, but in three dimensions. First, the patch may be drawn on plan instead of in perspective, as in Fig. 2, when its shape will be seen to be materially altered. The tail becomes long and pointed and the head, instead of being a thin wide stripe, becomes rounded. The relative sizes of the various zones have also altered; the end of the tail, which was conspicuous in perspective, is now insignificant, and the zones forming the head are relatively of much greater extent. The various zones are similarly shaded in each drawing.

A further step transfers the confines of the patch to the isocandle diagram, as shown in Fig. 3. In this projection the relative areas of the various zones are almost ludicrously altered. The tail is seen to be formed by a tiny zone of the light distribution which will hardly reproduce in the illustration, whereas the head is formed by a large area around the downward vertical. The apparent relative sizes of the various zones are quite altered and in some ways inverted.

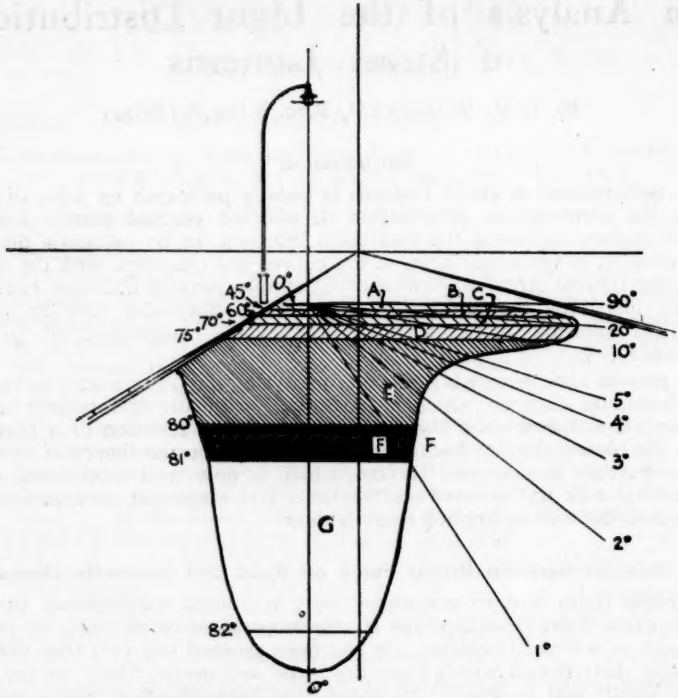


Fig. 1. Bright patch on road in perspective.

(1.1.) Effect of Side of Road

Lanterns may be on either the near or the off side of the road, and the region of the distribution responsible for forming the bright area varies slightly. The effect is shown in Fig. 3 by the dotted line, showing that the change, for straight roads of normal width, is small.

(1.2.) Effect of Distance of Lantern

Fig. 3 is drawn for a lantern at 300 ft. from the observer. If the process is repeated for lanterns at a series of distances and for each side of the road,

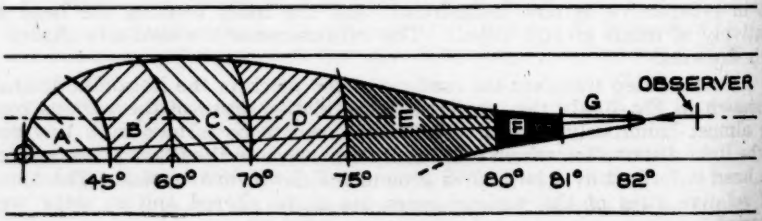


Fig. 2. Bright patch on road in plan.

a series of curves results as indicated in Fig. 4, which shows curves for lanterns up to 400 ft. distant. It will be seen that for straight roads it is possible to delineate two regions, as shown, enclosing the parts of the light distribution which are mainly responsible for the "heads" and for the "tails" of the bright patches. Of course, there are some parts of the distribution which are responsible both for the heads of the more distant patches and for the tails of the nearer ones, but in a general way the distinction may be made.

(1.3.) Effect of Bends

On bends, lanterns are mounted on the outside of the bend, and it is necessary for the light distribution to extend in plan towards the "street side"

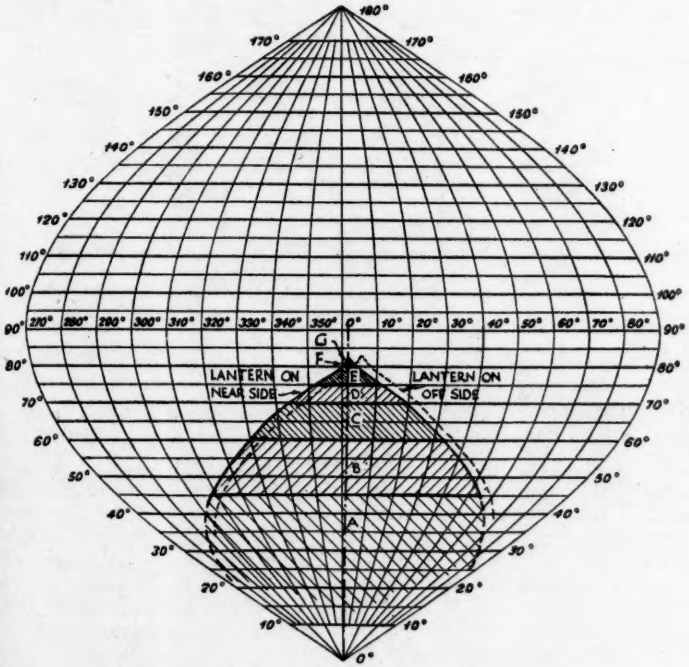


Fig. 3. Bright patch on road referred to isocandle diagram.

of the lantern in order that the bright patch shall be properly formed when seen by an observer who picks up the lantern as he comes around the bend. This is important, as in these circumstances the patch from the lantern is generally unaided by build-up from other patches, and has the important task of revealing the "apparent corner" which the driver particularly watches. In order to cater for bends, therefore, it is necessary that the areas which form the heads and the tails should be extended on the street side, as shown. It will be

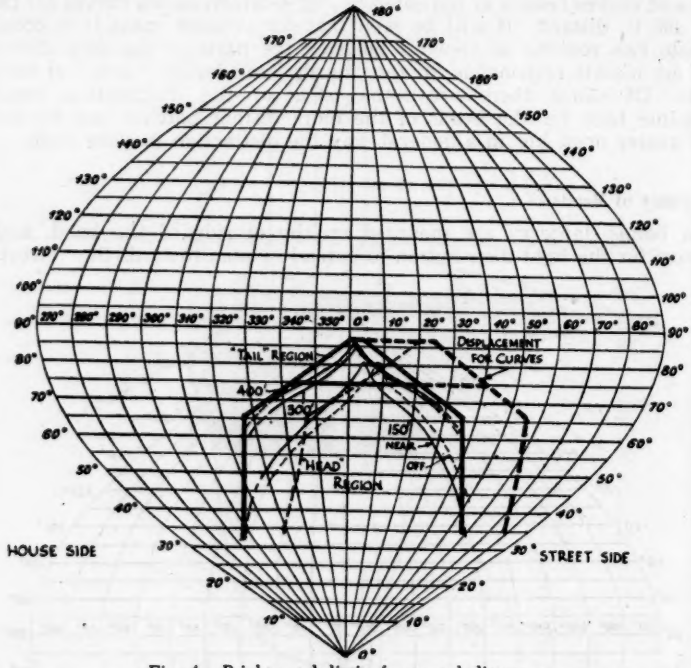


Fig. 4. Bright patch limits for several distances.

appreciated that the extreme right-hand side of the extension will be active only on very sharp bends.

(2) Glare

Hopkinson(4) has pointed out that the part of the distribution responsible for directing light into the eyes of road users can be shown by drawing a part of the isocandle diagram upside down on a perspective or photograph of the street. The converse is obviously possible; the position of the observer can be shown on the isocandle diagram when he is at various distances from the lantern and on either the near or the off side of the carriageway, and the corresponding parts of the distribution, which send light to his eyes, can then be read off. This has been done in Fig. 5. It will be seen that the glare lines occupy only a small part of the field, and that this part lies wholly within the "tails" region. Thus it is impossible to diminish the intensity which causes glare, without simultaneously reducing the brightness of the "tails" of the patches. The glare lines are stopped at 15 deg. below the horizontal, because at that angle the view of the lantern is usually obstructed by either the roof of a car or by a hat-brim. This angle is that usually chosen for cut-off, when such a distribution is used.

(3) Light on Buildings

It is generally agreed that a street lighting installation should illuminate the buildings at the sides of the street, and that the appearance of a lighted

street is enhanced by the presence of buildings which are light in colour, pleasing in appearance and well lighted. The absence of buildings, or of any light on them, gives a depressing and gloomy effect and increases glare; unlighted buildings have a "tunnel" effect. The outlines of typical buildings can be added to the isocandle diagram following a well-known drawing due to Minchin (5) and are shown, with the footpaths, in Fig. 6. The outline has not been carried to infinity, inasmuch as there is no need to attempt to light buildings a long way down the street; they are adjacent to, and will be lighted by, lanterns in their vicinity. The building outlines have therefore been stopped at the point at which the illumination from the next lantern is equal to that from the lantern under consideration. They are set out for a straight road only; on bends they would occupy slightly different regions.

(4) Light for Pedestrians

Pedestrians are much concerned with the lighting of the footpaths, and they respond to the cheerful appearance of the lighted street. The candlepower and flux directed to the footpaths can be read from the diagram as indicated below. The cheerful appearance is related to the illumination in the neighbourhood of the lantern. A reasonably high illumination there, even if the remainder of the road is rather dark, gives an impression of well-being, and that there at

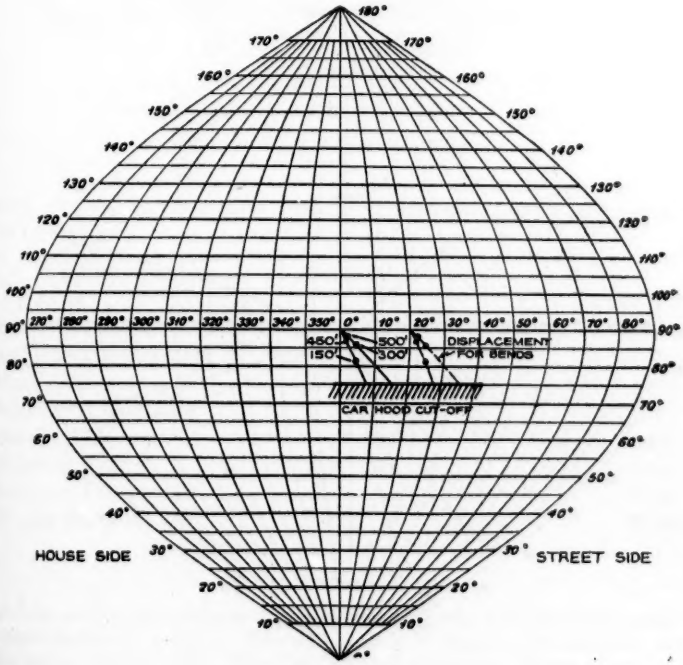


Fig. 5. Glare limits.

any rate one can see well, whereas if that light is redirected elsewhere and spread evenly over the road the effect is often more gloomy and more glaring. For this reason the region within 45 degress of the downward vertical can be assigned to " cheerful appearance."

(5) Analysing Diagram

The several diagrams here derived can now be combined into a single analysing diagram as shown in Fig. 7, which can be conveniently produced on transparent paper to the scale at which isocandle diagrams are usually drawn and laid over them. It is then possible to assess for a given lantern the candlepower, and if necessary the flux, which is directed to each of the various regions and to compare various lanterns more systematically than is possible with the unaided isocandle diagram. In order to obtain the flux, it is necessary to know the solid angles of the various zones of the diagram; they are tabulated in Table I below. The average candlepower in each of the zones, multiplied by the solid angle of the zone, gives the flux in that zone. It will be appreciated that some of

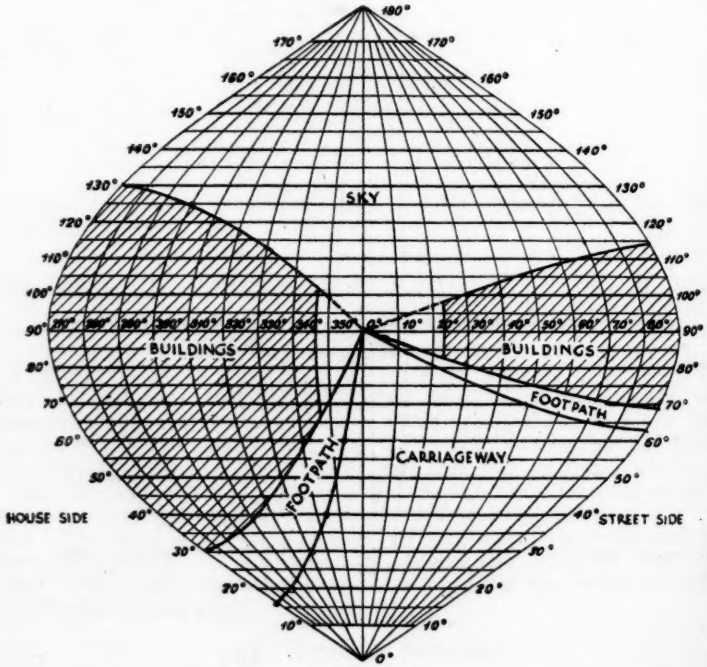


Fig. 6. Buildings and footpaths.

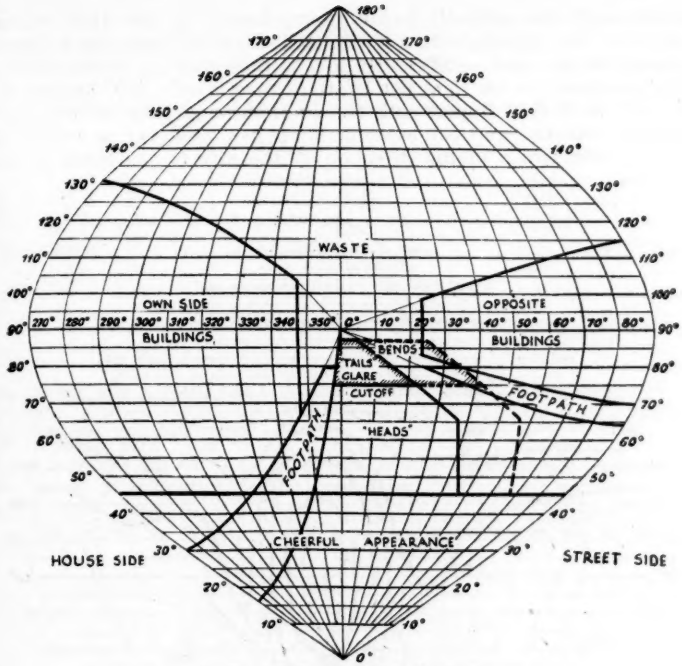


Fig. 7. Complete analysing diagram.

the zones overlap so that some regions of the space about the lanterns are covered twice over.

Table I

Region	*Solid Angle*
"Tails" and Glare	0.0466
Bends ("Tails" region)	0.0712
"Heads"	0.336
Cheerful Appearance	0.911
Near-side Buildings	1.685
Off-side Buildings	0.645
Near-side Footpaths	0.348
Off-side Footpaths	0.090

(6) Typical Result

An interesting comparison can be made between two lanterns made by the same manufacturer, using a 250 watt H.P.M.V. lamp, one burning vertically and the other horizontally. The light distributions are shown in the isocandle diagrams of Figs. 8 and 9, and the polar curves in vertical planes of Fig. 10.

The lantern with the vertically burning lamp has the greater light output ratio of 75 per cent.; the lantern with a horizontally burning lamp has a light output ratio of only 55 per cent.—sufficiently low to prejudice its use in traffic routes at normal spacings, for the light per 100 ft. of road is only 2,600 lumens at 150 ft. spacing, and the M.O.T. Report calls for a minimum of 3,000 lumens per 100 ft. The lantern with the vertical burning lamp has, however, a rather inferior light distribution which in the direction of the street axis tends to send too

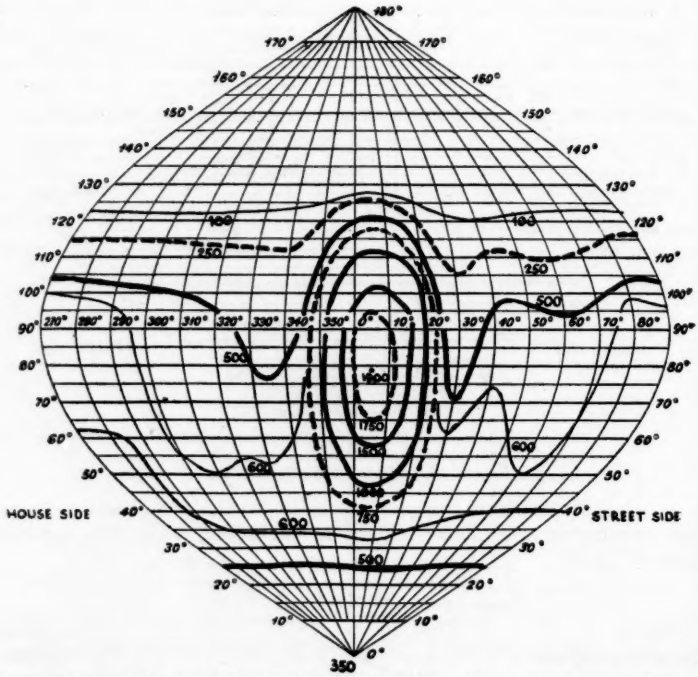


Fig. 8. Light distribution of street lantern with 250 W. vertically burning H.P.M.V. lamp.

much light above the horizontal. Each lantern, however, gives excellent results in practice when appropriately installed. The candlepowers in the various zones are shown in Table II.

It will be seen that in the important regions there is actually little to choose between the two lanterns. The vertically burning lamp lantern will form the tails of the more distant patches a little better; it will have perhaps a little less glare. The lantern with horizontal burning lamp forms the nearer patches better and is better on bends on the whole; it is more suited to short and regular spacing, and will call for more precise adjustment and maintenance. The heads of the patches will be almost exactly the same for the two; so will the cheerful appearance. The off-side buildings are similarly lighted, but the near-side buildings are poorly lit by the horizontally burning

Table II

Region	*Vertical Lamp Lantern*	*Horizontal Lamp Lantern*
"Tails" and Glare ...	1,500-1,900. Stronger for distant patches ...	1,200-2,250. Weaker for distant patches.
Bends	1,750-500. Weak on severe bends	1,800-1,000. Strong on severe bends.
Heads	1,200 (750-1,800)	1,200 (750-2,000).
Cheerful Appearance ...	350-700	500-600.
Near Buildings	500-600; even	100 (near)-1,500 (distant).
Off Buildings	500-600	200-700.
Waste	Some, near street axis	Little, except on distant buildings.

lantern, which has a solid back on the column side. The lantern for vertical lamps wastes some emitted flux; the lantern for horizontal lamps wastes little emitted flux but it emits less.

It appears that the low light output of the horizontally burning lantern appears as low illumination of the near-side buildings in the region near the lantern; in other respects there is very little practical difference in their per-

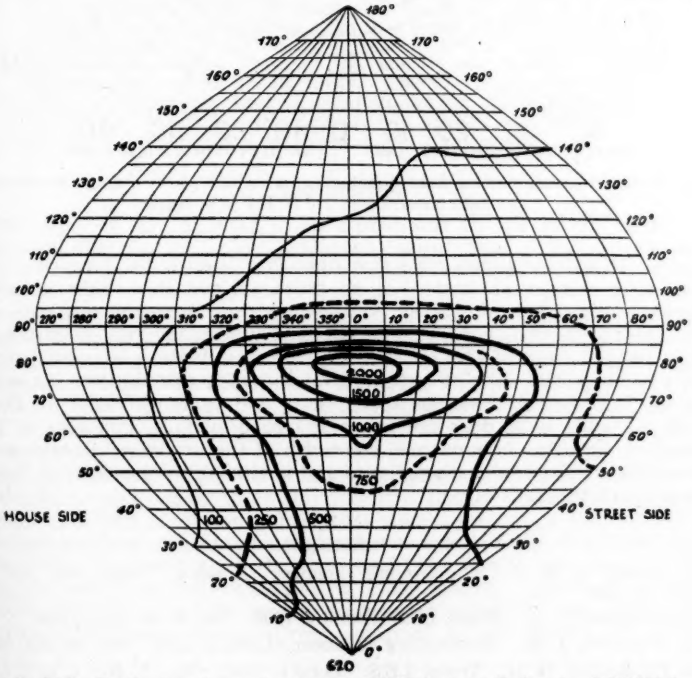


Fig. 9. Light distribution of street lantern with 250 W. horizontally burning H.P.M.V. lamp.

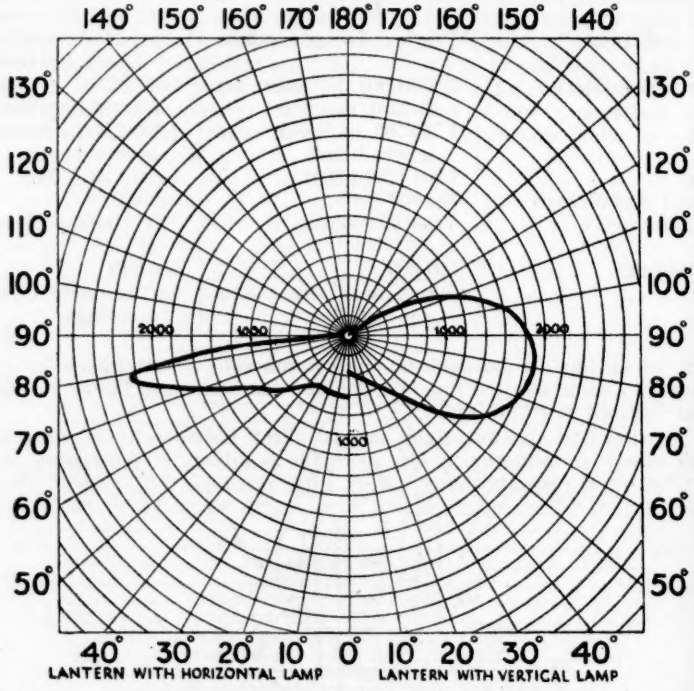


Fig. 10. Polar curves showing light distribution (in vertical planes through maximum) of two street lanterns with 250 W. H.P.M.V. lamps.

formance. It will be appreciated that light flux leaving the lantern in useless directions, or "external waste," is no more serious than light absorbed in the lantern, or "internal waste." The conclusion from this analysis is that in performance there is very little to choose between the two, notwithstanding the low light output of the horizontally burning lantern—a conclusion supported by experience. It also appears that the wide distribution characteristic of the horizontal lamp does not appear as a wide patch of light on the road; most of the wide peak does not reach the road surface, but goes to the far buildings at the side. In any case, the width of the bright patch is determined by the surface reflection characteristics and is almost independent of the width of the peak of the distribution.

References

(1) Walsh, J. W. T. Illuminating Engineer (London), 1933. Vol. 26, No. 7, p. 669.
(2) Waldram, J. M. Trans. I.E.S. (Lond.), 1938. Vol. 3, No. 11, p 165.
(3) Waldram, J. M. Illuminating Engineer (Lond.), 1934. Vol. 27, pp. 304, 339.
(4) Hopkinson, R. G. Trans. I.E.S. (Lond.), 1941. Vol. 5, No. 1, p. 1.
(5) Smith, F. C. Inst. Gas. E. Publication, No. 45, 1932.

Hot Cathode Tubular Fluorescent Lamp Circuit Analysis*

By E. WOOD, A.M.I.E.E. *(Member)*

Synopsis

It occurred to the author, some time ago, that a study of the fluorescent lamp circuit, coupled with a description of some practical tests, would be useful to people dealing with this new form of lighting. It had been apparent, and was forcibly brought out when work on the paper was proceeding, that a knowledge of A.C. theory was essential if one is to be able to understand thoroughly the fluorescent lamp circuit. But once having grasped such A.C. theory, leading to the better understanding of the circuit, it follows that the reasons for the inclusion of the component parts of the circuit such as choke and capacitor, etc., are made plainer.

The paper therefore describes the circuit and the lamp, as an introduction, and this information has largely been obtained from the various technical articles which have been published from time to time. The tests described are such as can be undertaken by anyone with the necessary instruments. The vector diagrams have been constructed from the results of the tests, and it has been assumed that the alternating quantities were sinusoidal. Although this assumption is not strictly correct it was considered that approximate vector diagrams so constructed would serve to illustrate the results satisfactorily. The conclusions drawn, it is hoped, will help lighting and installation engineers and others to a better understanding of this new type of lighting and the criticisms offered will, it is hoped, be taken in the right spirit.

Introduction

This paper is not intended to be a discourse on the design of fluorescent lamps or on the physics of the discharge lamp. That is left to the research people, who are much better equipped for that purpose. It has been written to give some information on the voltages, currents, and power factors found in the various parts of the 5-foot fluorescent lamp circuit. Some of the information has probably been given in the technical journals published from time to time, so your indulgence is requested for repeating what may be already known. In this respect a quotation from the "Electrical Review" of November 1, 1946, is useful. In that issue there is an article entitled "Fluorescent Lighting—Its Future in the Home." During his discourse, the speaker made these remarks: "... To ensure satisfactory operation the lighting should be considered as an essential and integral part of the architectural design, the quality of the auxiliary gear should be ensured by some standard and (this is the important part from our point of view) electrical contractors should acquire a full knowledge of fluorescent lighting circuits, coupled with the possibility of advice and tests by Electricity Undertakings." It is realised here that this is possibly treading on thin ice, and the author would hasten to add that for "electrical contractors" he would substitute "all personnel erecting or servicing fluorescent lighting, and to state that some electrical contractors do try to acquire full knowledge

* Paper read before Huddersfield Group of the I.E.S., January 14, 1947.

of the fluorescent lamp circuit and are successful in that respect." As regards advice by the Electricity Undertakings, while it is true that most Undertakings do give advice to whoever desires it, the opinion is expressed that they are not at the moment in a position to answer every query that may be put on fluorescent lighting. Some of the questions could only be answered by an expert. With regard to tests, the tests which have been carried out by the Huddersfield Electricity Department form the subject of this paper; they were carried out some time ago, and seem to have anticipated the speaker already referred to.

Some knowledge of A.C. theory is essential in order to visualise what is happening when resistances, inductances, and capacitors are connected in series and parallel to alternating current supplies.

After much research, electric lamp manufacturers introduced, about 1937, the 5-foot fluorescent lamp as we know it to-day(1). It depends on the passage of an electric current through mercury vapour at low pressure contained in a glass tube coated with fluorescent powder, and into each end of which has been sealed an electron emitting electrode. The impedance of the discharge across the mercury vapour to the passage of electricity decreases with increase of current so that an external impedance connected in series with the tube is necessary to produce stable running conditions.

The manufacturers stated that much consideration had been given to the best form of lamps, identity of main characteristics, and complete interchangeability of the component parts of the lamp circuit. On the latter point the results have not been entirely successful, e.g. there are at present three forms of starter switch available none of which can be substituted for the other, and the 4-foot lamp, recently introduced, has bi-pin caps in the place of the bayonet caps of the 5-foot lamp.

In the fluorescent lamp circuit a starter switch short circuits the tube and joins the electrodes in series with the choke across the supply mains when first switched on. The current heats the electrodes to the required temperature and the switch is designed to open the circuit when this has occurred. There are two types of starter switch, each having bi-metallic elements. In one case the heating is obtained from a glow discharge between them while in the other a separate heater coil is provided. The glow starter switch contact tips are normally open. When current is supplied to the circuit, a glow discharge forms round the bi-metals, heating them, and causing the contacts to close. Current now passes to the electrodes. When the contact tips close the glow is short-circuited so that the glow becomes extinguished, the bi-metals cool down, and the contacts re-open giving the required voltage surge to start the lamp.

The thermal type starter switch has two normally closed contacts on two bi-metallic strip elements, one of which is placed near to the heater coil. When a potential difference is applied to the circuit, current passes through the heater coil, lamp electrodes, etc. The heat in the coil causes the contact tips to open thus giving the required voltage surge to start the lamp. It should be observed that the glow type switch is not in circuit when the lamp is in use, while the thermal type is, or rather the heater coil of the thermal switch is in circuit, its duty being to keep open the contact tips. This is a useful point to remember nowadays when materials are in short supply. Lamps operated by means of glow type switches can be successively started by one glow switch, the switch being connected to the lamps in turn.

It should be noted that the voltage surge is of the order of 800 to 1,000 volts so that cables used in fluorescent lamp circuits, especially flexibles, should be of good quality. The efficient earthing of metal fittings is also im-

portant, in the interests of safety, since there is always the possibility of the circuit being made alive while repairs are being executed, unless isolation can be guaranteed.

Tests

The following information has been obtained from tests made on tubular fluorescent lamps. The tests were made with ordinary commercial instruments, as distinct from laboratory instruments. The results obtained differ to a certain extent from those given by manufacturers. It is therefore suggested that these results should be taken with a certain reserve, since the manufacturers have better facilities for accurate measurement. It is interesting to note, however, that the latest figures for lamp voltage and current, for example, published by the manufacturers, are 106 volts and 0.85 amperes, whereas the original figures were 110 to 115 volts and 0.8 amperes. Perhaps the manufacturers will state whether there has been some difference in design of the components?

Single Lamp Circuit

Tests were made on a single lamp circuit (Fig. 1) using a tapped choke on the tapping to suit the supply voltage, viz., 230 volts. The supply voltage was maintained at 230 throughout the tests. The current lags behind the voltage by an angle of 81 degrees, or alternatively the voltage leads the current by the same angle.

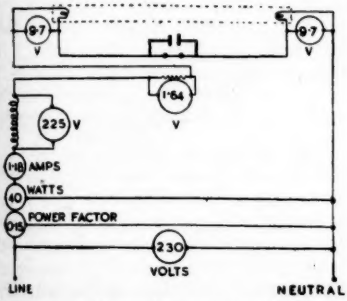


Fig. 1. 5-ft. single lamp circuit without power factor correction before starter switch opened.

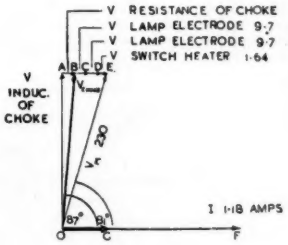


Fig. 2. Approximate vector diagram of circuit shown in Fig. 1.

The current in the circuit before the thermal switch opened was found to be 1.18 amps. The voltage across the switch heater was 1.64 volts.

Since this is a resistance load the product of voltage and current gives the watts expended in the switch heater. When the fluorescent lamp is switched on, at that particular instant, the choke, lamp electrodes, switch heater and switch contacts are in series, and therefore the current is common to all parts of the circuit. The watts expended in the switch heater were found to be 1.89.

The voltage across each of the lamp electrodes before the switch opened was 9.7 volts. Since this is a resistance load the watts in this part of the circuit were found to be, by the product of volts and amps, 23.0 watts.

The total calculated power was 36.3 watts. The wattmeter reading was 40 watts. The discrepancy may be due to the choke having warmed up a little since resistance increases with rise in temperature.

The power factor of the circuit calculated from wattmeter, voltmeter, and ammeter readings (40 watts, 230 volts, 1.18 amps) gives a value of 0.147. The power factor meter reading was 0.15.

The vector diagram of the circuit in these conditions is shown in Fig. 2.

Since it is a series circuit the datum vector is that of the current, to which the various voltage vectors must be related. The choke voltage is leading by 87 degrees. The voltages of switch heater and lamp electrodes are in phase because they are resistance loads. The angles in the diagram are not to scale but the voltages and currents are.

The current is that due to the supply voltage applied to the total impedance of the circuit, which is the vector addition of the separate impedances in the circuit before the switch opens. OF is the current vector, OA represents the voltage across the inductance and is leading the current vector by 90 degrees. AB is the voltage across the resistance of the choke and is in phase with the current. BC and CD are the voltage vectors of the lamp electrodes, again being resistance loads, in phase with the current, and DE represents the small

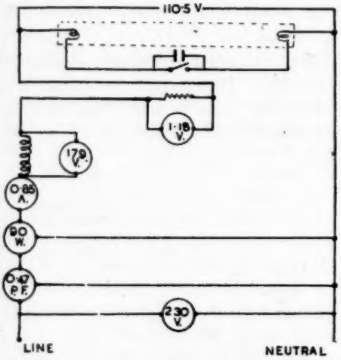


Fig. 3 5-ft. single lamp circuit without power factor correction, after starter switch opened.

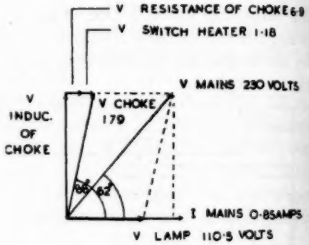


Fig. 4. Approximate vector diagram of circuit shown in Fig. 3.

voltage vector of the switch heater. The OB vector leads that of the current OF by 87 degrees. OE is the vector sum of the separate voltages and must be the supply voltage. It leads the current vector by 81 degrees. OG is equal to the sum of AB, BC, CD, and DE, and is known as the " in phase " component, in this case it is the component of the voltage in phase with the current. OG to the voltage scale represents 33 volts and this value multiplied by the current 1.18 amps gives 38.94 watts.

The conclusions to be drawn from these results are, that the choke has practically the whole of the supply volts across it for the time taken for the switch to open, the voltages across the lamp electrodes are of the order of 10 volts and the voltage across the switch heater is 1.64 volts. The circuit is taking power at the rate of about 40 watts while the volt-amps are of the order of (1.18 amps 230 volts) 270 at a power factor of 0.15.

The next considerations are of the various parts of the circuit after the switch has opened, resulting in the arc being struck and the lamp in its normal working condition. (Fig. 3.)

The current was 0.85 amps. The potential differences across the choke and switch heater were 179 and 1.18 volts respectively, and the watts expended in the choke and switch heater were 5.9 and 1.0, giving a total 7 watts. The potential difference across the lamp was 110.5 volts. The current through the

lamp is in phase with this potential (this can be shown by oscilloscope) but the volt-amps do not represent watts because of the power factor of the lamp due to the wave form not being sinusoidal. Means of actually investigating either the watts or the wave form were not available but taking the manufacturer's figure of 0.9, the lamp watts would be 84. The total watts of the circuit would thus be 91 watts. The wattmeter reading gave a value 93 watts. The calculated power factor is 0.47; power factor meter reading 0.47. Fig. 4 is the approximate vector diagram of the circuit shown in Fig. 3.

The power factor of a circuit, if it lags, can be improved by connecting capacitors in parallel. Fig. 5 shows the 5-foot lamp circuit with power factor correction.

It should be noted that currents, voltage drops, and watts in the circuit beyond the capacitor are substantially the same as they are in a circuit without power factor correction. From the tests taken, the lamp voltage drop was slightly less (107 against 110.5) the switch heater drop and choke drop were slightly higher (1.2 against 1.18 and 183 against 179). Theoretically there should be no difference. Fig. 6 is the approximate vector diagram of the circuit shown in Fig. 5.

The introduction of the capacitor tends to introduce harmonics. An increase in harmonics in the circuit tends to be damped by the choke.

The current through the choke, lamp, and switch heater was as before 0.85 amps. Again assuming a lamp power factor of 0.9 we have the lamp watts 81.8, and total watts 93.5. The current in the capacitor circuit was 0.57 amps. The calculated power factor was 0.82, the measured power factor was 0.86. (See Figs. 7 and 8.)

Twin Lamp Circuit

As mentioned previously twin lamp circuits have been developed to lessen the objectionable effects due to stroboscopic flicker when single phase supplies only are available. The circuit consists of a choke stabilised circuit and a choke-capacitor stabilised circuit so designed that the respective lagging and leading currents when combined give a resultant current which is almost exactly in phase with the supply voltage, thus giving a power factor approaching unity. (Wiring diagram, Fig. 9.) The inductive branch uses the normal choke. A study of the vector diagram points to the conclusion that a capacitance only

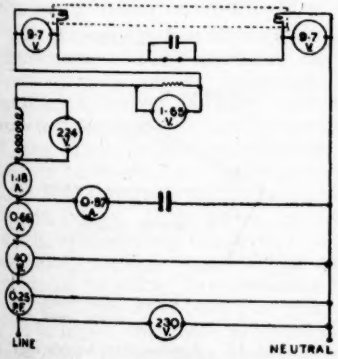


Fig. 5. 5-ft. single lamp circuit with power factor correction, before starter switch opened.

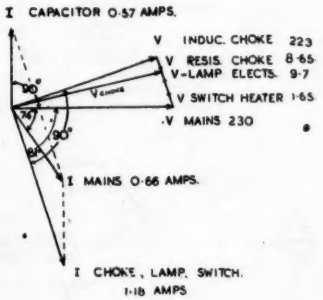

I CAPACITOR 0·57 AMPS.
V INDUC. CHOKE 223
V RESIS. CHOKE 8·65
V-LAMP ELECTS. 9·7
V SWITCH HEATER 1·65
V MAINS 230
I MAINS 0·66 AMPS.
I CHOKE, LAMP, SWITCH. 1·18 AMPS

Fig. 6. Approximate vector diagram of circuit shown in Fig. 5.

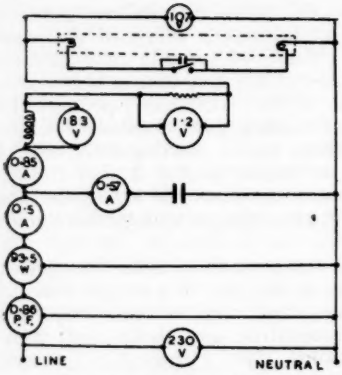


Fig. 7. 5 ft. single lamp circuit with power factor correction, after starter switch opened.

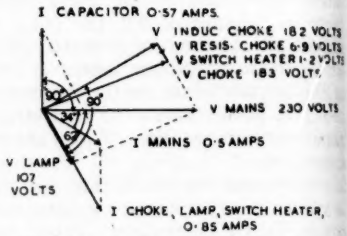

I CAPACITOR 0·57 AMPS.
V INDUC CHOKE 182 VOLTS
V RESIS. CHOKE 6·9 VOLTS
V SWITCH HEATER 1·2 VOLTS
V CHOKE 183 VOLTS
V MAINS 230 VOLTS
I MAINS 0·5 AMPS
V LAMP 107 VOLTS
I CHOKE, LAMP, SWITCH HEATER, 0·85 AMPS

Fig. 8. Approximate vector diagram of circuit shown in Fig. 7.

stabilised circuit in combination with an inductance stabilised circuit should give the required result. The vector diagram of such a circuit would be as shown (Fig. 9). Assuming a lamp voltage drop of 106 volts (manufacturer's figures) the angle of lead of lamp volts on supply volts would be of the order of 60 degrees, and from the vector diagram the capacitor volts would have to be 204. The capacity of the capacitor required would be 13.2 mF. (2).

$$C = \frac{I}{\omega V} = \frac{0.85}{314 \times 204}$$

Capacitor only stabilisation introduces problems of circuit stability and wave form especially at normal supply frequencies. In general the wave form of this type of circuit is of a very peaky nature and, since the light output of the

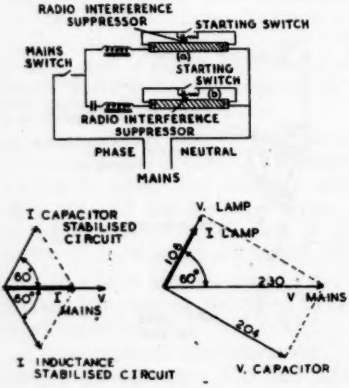


Fig. 9. Wiring diagram of twin lamp circuit, and vector diagrams.

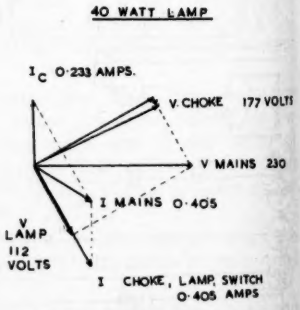


Fig. 12. Approximate vector diagram of 4-ft. single lamp circuit with power factor correction, after starter switch opened.

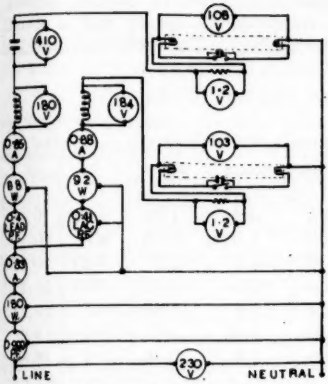


Fig. 10. Twin 5-ft. lamp circuit after starter switch opened.

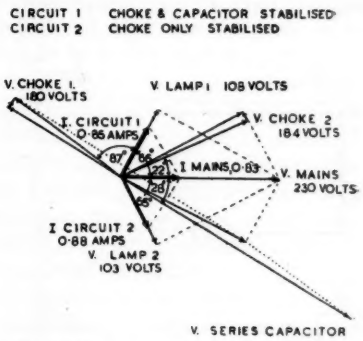


Fig. 11. Approximate vector diagram of circuit shown in Fig. 10.

lamp depends on the current through it, flicker becomes more pronounced. Stable operation can be obtained by connecting in series with the capacitor an inductance which limits the current peak. Connecting an inductance and a capacitor in series gives the condition of two voltages 180 degrees in phase relationship, the resultant voltage being that of capacitor volts minus inductance volts. On the 230 volt tapping the inductance volts are about 180. The volts across the capacitor would therefore be 204 plus 180 = 384 volts. The capacity of such a capacitor to ensure that the current in the capacity circuit would be 0.85 amps at 384 volts is

$$C = \frac{0.85}{314 \times 384} = 7.04 \text{ mF.}$$

Fig. 10 shows the practical twin lamp circuit and test results using 5-foot lamps, and Fig. 11 the approximate vector diagram of such a circuit.

Fig. 12 is the approximate vector diagram of the 4-foot single lamp circuit with power factor correction after the starter switch opened.

It cannot be too strongly emphasised that it is important to make the connections of the fluorescent lamp circuit correctly. While it is a comparatively simple job to substitute a fluorescent lamp fitting, complete with auxiliaries, for an ordinary pendant fitting, unless it is particularly checked for correct polarity, trouble may afterwards occur, which may result in failure of new lamps or starter switches. In Fig. 13, if the "live" and earthed conductors have been wrongly connected, as shown, to D and E respectively, the lamp will function quite correctly so long as the insulation resistance values remain intact. If, however, an earth fault develops at A then on closing the switch, immediately the supply voltage (230) is applied to the electrode F. The maximum voltage experienced across this electrode in the tests was in the region of 10 volts. It is obvious that the electrode will be destroyed. If the fault occurred at B both electrodes would be burnt out, while if it occurred at C it is likely that both electrodes and switch heater would fail. There is the possibility in the latter case that the switch may operate and open the circuit. It must be remembered that usually one pole of the supply is connected to earth. An attempt was made in the following manner to ascertain what value

of applied voltage would cause failure of either electrodes or switch heater. The switch heater and two electrodes were connected in series and a small voltage applied, the voltage being gradually increased. The results obtained

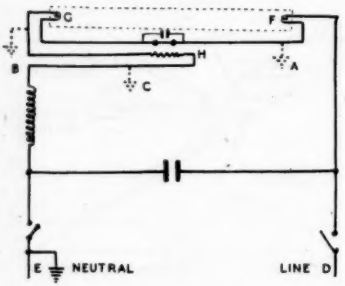


Fig. 13. False connection of supply mains, single lamp circuit.

Mains Volts	Current Amps	Heater Volts	Electrode Volts	
			1	2
18.5	0.8	1.24	8.47	9.45
20.0	1.0	1.45	8.6	10.1
21.6	1.1	1.6	9.23	10.73
23.0	1.21	1.73	9.65	11.4
24.4	1.3	1.85	10.1	12.1
32.0	1.45	2.1	12.0	15.8
33.0	1.5	2.16	12.4	16.8

Fig. 14. Voltage required to cause failure of switch heater.

are shown in Fig. 14. A very small increase in voltage caused the current to rise to approximately 5 amps, and the switch heater failed.

The two lamp electrodes were then connected in series and the voltage applied as before. As it gradually increased, the current increased in approximate proportion until a point was reached when a small increase in voltage resulted in a large increase in current. It is probable that at this point the gas in the tube became ionised and so passed some of the current. More than 12 amps were passed at one period, the electrodes still remaining intact. Another method was then adopted. The adjustment to the voltage was made while the circuit was disconnected from the supply, i.e., a voltage was applied and readings taken, then the current was switched off and the increase in voltage made, the current then being switched on. This was probably more like service conditions. In this manner a number of lamp electrodes were fractured, the voltage required varying between 25 and 40 volts depending on the condition of the individual lamp. The supply voltage is obviously much in excess of the voltage required to destroy the electrodes.

The capacitor should be connected directly across the supply mains not as shown in diagram (Fig. 15). If it has been so connected the lamp wattage will be considerably increased and result in early failure of the lamp. Should the lamp be removed we have the condition of a choke and a capacitor in series. The voltages across the choke and the capacitor would be 180 degrees apart. Because the choke has resistance this does not happen, but it is very likely that a high voltage would be found across the capacitor. The vector diagram, Fig. 16, has been constructed from the results taken at 230 volts. The circuit has a power consumption of 12 watts. It may be argued that it is unlikely that this may occur, but while ever there is a possibility of such a fault it is essential that it be guarded against when making connections in the fluorescent lamp circuit.

Tests were taken to find out at what voltage the lamp became extinguished. It would seem that there should be no difficulty in this respect if the supply voltage is kept within the statutory limits of $\pm$ 6 per cent. of the declared voltage.

Frequency Variation

It was difficult to obtain accurate results due to variation in frequency since no means of effecting this variation was available. Some figures were obtained when the frequency varied on account of heavy load conditions on the supply system. As was to be expected the impedance of the choke varied in inverse proportion to the frequency so that with decrease in frequency an increase in current was experienced. It would appear that a decrease in frequency accompanied by a decrease in supply voltage would tend to neutralise each other since it is natural to expect a decrease in current due to a decrease in voltage. As decrease in voltage and frequency are usually the first effects noticed in these days of abnormal loads, which cannot always be met, it is comforting to find that they tend to cancel each other.

Starting by resonance methods is not common in this country, as yet, but as one never knows just what line the manufacturers may decide to adopt, perhaps it might be of interest briefly to outline the method.

The object of producing resonance is to apply a comparatively large voltage across the lamp to initiate the discharge, and therefore series resonance is employed.

Series Resonance

Consider a series circuit consisting of resistance, inductance, and capacitance, as shown in Fig. 17. The resultant reactance is given by $\omega L - \frac{1}{\omega C}$ so that if the values of L. and C. are so arranged as to make the inductive reactance equal the capacitive reactance, i.e., $\omega L = \frac{1}{\omega C}$, the resultant reactance is zero and the impedance of the circuit is the same as the resistance. In this condition, if the inductive and capacitive reactances are greater than the resistance, the voltages across the coil and capacitor will be many times greater

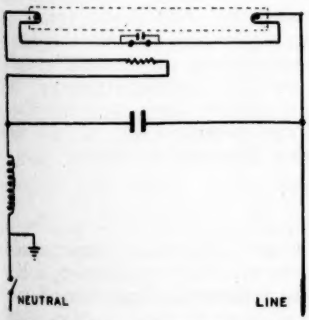


Fig. 15. False connection of P.F. correction capacitor, single lamp circuit.

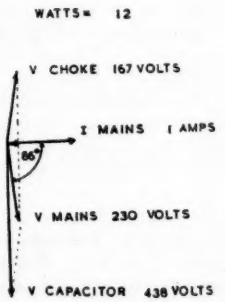


Fig. 16. Vector diagram of choke and capacitor in series connected to 230-volt supply mains.

than the applied voltage and the circuit is said to be in a state of resonance. The vector diagram is as shown where VL=voltage (induc.) VC=voltage (capac.) and since VL=VC the applied voltage VM=VR the voltage across the resistance. Resonance occurs when $\omega L = \frac{1}{\omega C}$ or $\omega^2 LC = 1$ $\omega^2 = \frac{1}{LC}$ hence since $\omega = 2\pi f$, $f = \frac{1}{2\pi\sqrt{LC}}$. This value is know as the resonance frequency. By suitable variation of L and C the supply frequency can be made to become this resonance frequency. As the resonance frequency approaches the supply frequency the choke voltage and capacitor voltage rise above the supply voltage and the current increases accordingly. Hence the circuit can be designed to provide a suitable cathode heating current and an adequate striking voltage until the lamp starts. The condition for resonance

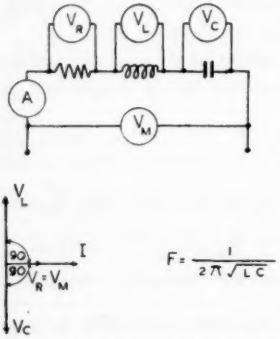
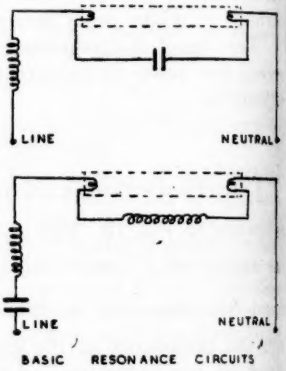


Fig.17. Resistance, inductance and capacitance in series and resultant vector diagram.



BASIC RESONANCE CIRCUITS

Fig. 18. Basic resonance circuits.

now no longer exists and so the comparatively high voltages across the choke and capacitor disappear. Fig. 18 shows basic resonance circuits. Starting, with this type of circuit, is said to be very satisfactory, the chief disadvantage is the high voltage which remains across the lamp if, for any reason, the lamp fails to start. We are told that the associated control gear on normal supply frequencies is somewhat bulky and expensive. Great simplification in the gear for resonance circuits can be achieved for higher frequency supplies. This would appear to be the reason for the 500 cycles/second adopted for the installation of fluorescent lighting on the Jubilee Tramcar belonging to the Sheffield Corporation.

Faults

No attempt is made to list all the faults which are likely to be experienced in connection with fluorescent lamps. Manufacturers have published a list of these with probable causes and remedies. The following suggestions serve to summarise the more common faults.

Lamp renewals are required when:—

1. Blackening of the lamp is observed at the ends.

2. Lamp flickers or blinks with shimmering effect along the tube.
3. Spiral movement of rings along the tube and low output.
4. Lamp appears dead. Examine for broken filament before replacement.

Faulty starter switch suggested and renewal required when:—

1. Flickering is present. Switch tending to switch off and on.
2. Lamp does not light, but both filaments glow. Switch contacts have welded or short circuited.
3. Lamp does not light and only one filament glows. Thermal switch faulty. Starter contacts not closed.
4. Too rapid operation of switch. Filaments fail to heat up.
5. Heater coil of thermal switch burnt out (perhaps due to broken lamp filament).

Suppression capacitor faulty:—

Short circuited suppressor unit cuts out switch so both filaments glow. If one filament glows an earth fault on suppressor unit or its wiring is suggested.

The life of the lamp is affected by operating conditions. Frequent starting causes loss of emission from electrode material and the amount of emission determines the life of the lamp. Fifteen per cent. below normal line volts, cold draughts, and low surrounding temperature produce flickerings which may wrongly suggest lamp renewal. Test for these.

Generally it is good policy to disconnect a circuit giving trouble from the supply unit until it can be corrected. If the switch is thought to be faulty disconnect it and try it in a good circuit when it will be judged to be in good order or faulty. If the switch is found to be correct test the tube in a good circuit to see if the fault is in the tube.

Never try a good tube in a defective circuit.

Conclusions

The development of the fluorescent lamp represents an advance in the science of lighting and makes it necessary for us to revise our ideas considerably from accepted methods of lighting practice. It is not, however, an ideal light source to suit all situations. It is not suitable, for instance, where a point source of light is required, such as projector lamps, nor is it adaptable, at the moment, to positions where the light needs to be dimmed, such as stage lighting.

Simplification, or, better still, complete elimination of the control gear, needs to be given some thought. The manufacturers have made a big mistake, in the author's opinion, in not standardising all the control gear of the fluorescent lamp circuit, especially those components which are likely to need replacement. It is probable that there will be available a bi-pin 80-watt lamp along with the bayonet cap type. At the moment there are at least three types of thermal switch, none of which can be substituted for the other. Why could not this type of switch have been standardised like the glow type with its S.B.C. fitting? The manufacturers may have good reason for all this, but to the user it is most annoying.

In the author's opinion manufacturers, installation engineers, and supply engineers should all have been allowed to express their points of view with regard to this standardisation. After all, "Genius alone starts things, but it takes labour to finish them," is a saying with a vast amount of truth in it.

The figure of 80 watts is very misleading. While it is true that the power

expended in the lamp itself is in the region of 80 watts, that for the whole circuit is between 90 and 95 watts for the 5-foot lamp, and 50-55 watts for the 4-foot lamp. As comparisons are generally made taking the figure of 80 watts, this is quite inaccurate and unfair to the metal filament lamp.

Fluorescent lamps should only be fixed by personnel who have a knowledge of the circuit sufficient to ensure the correct connections without any possibility of doubt. This is important since any fault developing later should not result in damage to the component parts of the circuit. It should be appreciated that a fault such as a short circuit or a low resistance earth, unlike a similar fault on a tungsten filament lamp circuit, may not operate the protecting device, fuse, etc., since the choke will limit the fault current to a value normally taken by the lamp. While this may not be serious it is a point that should be appreciated by anyone undertaking a repair. On high voltage tubes this will be more serious, and some thought should be given to the production of some device for automatically isolating such circuits on a fault developing.

Capacitors were in short supply during the war, in fact they were not allowed for power factor correction. A number of fluorescent lamps were installed without them. Steps should be taken to remedy this omission at the earliest opportunity, both from the consumer's and the supply authority's point of view. Some people regard power factor like earthing, as a necessary evil, although they cannot, as a rule, leave it to the apprentice to remedy as a punishment for his wrongdoing. It has been shown that fixing capacitors for power factor correction decreases the line current by about 40 per cent. This means that besides eliminating overloading of cables with wattless current, the voltage drop on the lamp circuit can be decreased by 40 per cent. if the capacitors are fixed at the lamp or near to it. In these days of load shedding when statutory limits sometimes go by the board, this voltage drop may become critical.

There are various opinions on harmful aspects of the stroboscopic effects from fluorescent lamps. In the author's opinion it can be so important as to need some modification if used with constant speed moving objects or indeed some variable speed moving objects. If it has any detrimental effect on eye-sight, that is something left to those more competent to judge. There are various opinions for and against in this respect.

The author wishes to thank Mr. F. A. Ellis, M.I.E.E., M.I.Mech.E., M.I.F., Borough Electrical Engineer and Manager of the Huddersfield Corporation Electricity Department for the permission he willingly gave for the use of apparatus and instruments in connection with the preparation of this paper; also to members of the Electricity Department staff who have helped with the tests and preparation of demonstrations, without which it would have been much more difficult, indeed perhaps impossible for the attempt to have been made. It is hoped that the effort will have been the means of making a little clearer some of the more intricate points about the fluorescent lamp circuit.

References:

(1) "Fluorescent Lamps." L. J. Davies, H. R. Ruff, W. J. Scott, Journal I.E.E. Vol. 89, Part 2, No. 11, Oct. 1942.

(2) "Circuits for Discharge Lamps." R. Maxted, J. N. Hull, Trans. Illum. Eng. Soc. Vol. X, No. 10, Oct., 1945.

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The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

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The following applications for Fellowship have been accepted:—
A. D. S. Atkinson, S. S. Beggs, E. A. Fowler, E. N. Lockyer, A. J. Ogle.

SESSION 1947—1948

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